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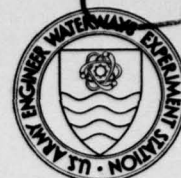
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EFFECTS OF THE NEW MADRID EARTHQUAKE SERIES IN THE MISSISSIPPI ALLUVIAL VALLEY

by

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20. ABSTRACT (Continued)

phenomena have not been the subject of detailed geological investigations applying knowledge of alluvial morphology and earth sciences methodology.

Comparative aerial photo interpretation has been used to classify liquefaction phenomena according to morphology, distribution, and relationship to major depositional environments. Surface morphology and spatial distribution of sand blows and fissures indicate basic control by drainage lines, water table position, and thickness of fine-grained topstratum deposits. Research efforts have been aimed at locating field test sites where the subsurface expression of the liquefaction phenomena can be investigated through trenching and land planing. Subsurface expression is presumed to be more permanent than surface expression and may permit the recognition of such features in older formations. Evidence of fissures and related phenomena is being sought in older Quaternary deposits to permit estimates of the frequency of past major earthquakes. Similarly, fissuring, sand extrusion, and ground disturbance are being sought in the numerous archaeological sites in the alluvial valley area to permit identification of major earthquakes during the past 4000 to 6000 years or more.

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PREFACE

This paper represents a slightly modified (edited for publication) version of a presentation made in the technical session entitled, "Problems of Engineering Geology along the Mississippi River," held on 13 November 1973, as part of the 1973 Annual Meeting of the Geological Society of America, Dallas, Texas.

The presentation in essence is a progress report on a study conducted within the Engineering Geology and Rock Mechanics Division (formerly Geology Branch), Soils and Pavements Laboratory (SPL), U. S. Army Engineer Waterways Experiment Station (WES), under the sponsorship of the Office, Chief of Engineers. A consideration involved in the decision to publish the presentation is the fact that the study was terminated shortly after the presentation was prepared and hence reflects the more significant results and conclusions obtained. The writer served as principal investigator on the study and prepared this paper under the direct supervision of Dr. C. R. Kolb, Chief of the Geology Branch (retired), and under the general supervision of Mr. J. P. Sale, Chief of the SPL.

Directors of WES during the preparation and presentation of this paper were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE; Technical Director was Mr. F. R. Brown.

EFFECTS OF THE NEW MADRID EARTHQUAKE SERIES
IN THE MISSISSIPPI ALLUVIAL VALLEY

By

Roger T. Saucier

1. On 16 December 1811 one of the North American continent's most severe and most widely felt earthquakes occurred not in California or Nevada or Alaska, but in northeastern Arkansas and southeastern Missouri.

2. A recent reevaluation of historical accounts of the earthquake has been made, prompted by increased interest in eastern U. S. seismicity generated by nuclear power plant design considerations. The data reevaluation indicates that the December 1811 earthquake was felt over an area of two million square miles extending from the Great Lakes to the Gulf and from the Great Plains to the Atlantic Coast (Figure 1).

3. Due to the largely uninhabited nature of the area near the probable epicenter, accurate data on the earthquake and ones that followed are largely absent. However, records kept at Louisville, Kentucky, indicate that as many as 2,000 shocks occurred within a year after December 1811. Of these, over 100 were major events and at least two others, occurring on 23 January and 7 February 1812, rivaled the first as far as intensity is concerned. Each of the three largest earthquakes had a Modified Mercalli Scale intensity of at least X, and possibly XII, and the three together comprise what is commonly thought of as the New Madrid Earthquake.

4. The area most devastated by the earthquakes is essentially coincident with the St. Francis Basin segment of the Lower Mississippi Valley. This is a 5,700-square mile area of low relief and very poor drainage, and although now cleared and cultivated, it was originally forested sandy prairies intermixed with swampy depressions. The basin is bounded on the west by Crowleys Ridge and on the east by the Mississippi River, and all drainage is to the south by way of the St. Francis River which flows into the Mississippi near Helena, Arkansas (Figure 2).

5. Habitation and utilization of the basin would be impossible without extensive flood control measures. Considering only Federal projects, there are 860 miles of channel and drainage improvements and over 700 miles of levees. Even with these, nearly 300 square miles of the lower part of the basin were inundated by backwater flooding during the spring of 1973.

6. Geologically, the basin consists almost entirely of Wisconsin Stage or younger alluvial sediments deposited by the Mississippi and Ohio Rivers. Areally, more than half of these comprise low terraces formed by braided streams carrying large quantities of glacial outwash (Figure 3). Because of progressive valley degradation during the Wisconsin Stage, older deposits form the higher terraces and ridges in the basin, mostly along its western side.

7. The eastern side of the basin is characterized by sediments laid down in point bar, natural levee, abandoned channel, and abandoned course environments of deposition in the present and relict meander belts of the Mississippi. Since changing from a braided to a meandering regime, the river has been aggrading and has produced a prominent meander belt ridge.

8. Excluding only those in abandoned channel and course environments, all deposits in the basin are characterized by a topstratum of clays and silts a few feet up to a few tens of feet in thickness. Beneath the topstratum is a massive sand and gravel substratum varying from 50 to more than 200 ft in thickness. This downward-coarsening, cohesive-noncohesive sequence was the most significant factor in the response of the area to the New Madrid earthquake.

9. Eyewitness accounts of the earthquakes are generally restricted to the Mississippi River and the vicinity of New Madrid, the only town of any consequence in the area at the time. These mostly involve bank caving, ground and water surface motion, sand blows or eruptions through earth fissures, and surface flooding (Figure 4). Most of the reported surface effects away from the river did not come about until decades later when geologists and naturalists first described the region.

10. The most comprehensive treatise on the earthquakes was published in 1912 by Fuller and involved a matching of historical accounts

and after-the-fact observations. Surface effects reported by Fuller and others, including such phenomena as widespread subsidence and uplift, were accepted without question for many years.

11. In 1964, the U. S. Army Engineer Waterways Experiment Station began a systematic program of detailed engineering-geologic mapping of the St. Francis Basin on a 15-min quadrangle base. As a result of this first new look at the area in at least 20 years, with appreciable new data and differing concepts of valley stratigraphy, it is apparent that several major reported surface effects have been incorrectly attributed to the earthquakes.

12. The first discrepancy to appear was the determination that neither the Blytheville Dome nor the smaller one to the southwest exist as structural features either at the surface or in the subsurface. In fact, some doubt still remains as to the precise mode of origin for the Tiptonville Dome, one of the more generally accepted earthquake effects.

13. A second major discrepancy emerged when this writer was able to demonstrate that the widely known St. Francis Sunk Lands were in existence long before the New Madrid earthquakes (Saucier 1970). Rather than being due to ground subsidence, the sunk lands originated 1200 to 1500 years ago when a much older, relict braided-stream channel was dammed by natural levee growth along a Mississippi River crevasse channel (Figure 5). The resultant ponding of local drainage created the lakes and swamps of the so-called sunk lands. Existence of these and similar features long before 1811 recently has been further substantiated by dendrochronological and archaeological studies.

14. These types of evidence casting doubt on the accuracy of reported effects of the earthquakes emerged at a time when the Corps of Engineers was entering a period of major reevaluation of earthquake design for dams and other structures. Particular interest was taken in the central U. S. where time-history records of major earthquakes are totally lacking and where earthquakes differ greatly in character and effects from those in the western U. S.

15. The New Madrid region is additionally of special concern because of its seismic history. With nearly 100 earthquakes having been

recorded since 1816, it is by no means an aseismic area (Figure 6). However, in view of the relatively low magnitudes and intensities of these, it would certainly be classed as a minor seismic region were it not for the dramatic events of 1811 and 1812. Hence, questions are immediately raised as to the recurrence intervals of truly major earthquakes, and whether there could be aseismic or minor seismic regions elsewhere in which devastating earthquakes are quite possible but simply have not occurred during man's brief recorded history.

16. As a step toward resolving some of these questions, the Waterways Experiment Station initiated in 1971 a study to intensively examine certain effects of the New Madrid earthquakes.

17. Principal attention in this study is being focused on the sand blows, fissures, and related phenomena caused by the liquefaction of shallow subsurface sand and its extrusion to the surface. These features were mapped by Fuller as extending over an area of 2500 square miles, and they are unquestionably the most widespread and significant effects correctly attributable to the New Madrid earthquake (Figure 4). In the present study, they are being classified and mapped at the surface and in the subsurface to establish recognition criteria. Their distribution and morphology are being related to surface geology, soils types, drainage patterns, and topography, to determine the relative susceptibilities of various deposits to liquefaction during earthquakes. Results of these efforts are being applied using geological and archaeological techniques to (1) definitively delineate the area affected by the earthquakes, (2) establish a more accurate epicentral position, (3) permit the possible recognition and delineation of other areas subjected to severe earthquakes, and (4) attempt to determine the recurrence rate of major earthquakes in the New Madrid region.

18. Unconsolidated sandy alluvium in areas with high water tables has been observed to liquefy during major earthquakes in all parts of the world. Where the sand is confined beneath a thin cohesive topstratum, it is typical for sand and water to extrude to the surface through single vents or linear fissures and form mounds or ridges (Figure 7). Depending on the nature of the sediments and the

magnitude of the earthquake, the extrusion may be a slow, continuous flow or a violent eruption sending sand and water several feet into the air.

19. As seen from the air in the St. Francis Basin area, liquefaction during the New Madrid earthquakes caused features ranging from single low circular mounds a few tens of feet in diameter to linear ridges thousands of feet long (Figure 8). It is typical for mounds to coalesce and in some areas the surface is covered with a sand sheet which may be acres in extent. Decades of cultivation have diffused all features and dramatic changes in appearance are evident even when comparing photography of the 1930's to that of the present decade.

20. Both the density and character of sand blows and fissures are highly dependent on local geology (Figure 9). The overwhelmingly dominant factor is the thickness of the cohesive topstratum. In most areas, greatest sand blow and fissure development closely reflects the thinner topstratum, hence giving rise to patterns such as those that follow and accentuate the ridges in a point bar ridge and swale sequence. Although not yet quantified and evaluated for regional significance, it is evident that certain unusually thick topstratum areas, such as in abandoned channels, preclude the surface appearance of liquefaction phenomena. Another step yet to be taken in the study is to relate this relationship to variations in drainage and topography. There are already strong suggestions that these factors can sometimes completely override the effects of topstratum thickness.

21. A highly significant result of the effects of topography and slope on the pattern of liquefaction was the widespread formation of fissures parallel to drainage lines. These are manifestations of bank caving and the lateral and down-slope movement of nearsurface deposits which, in effect, briefly floated on a layer of liquefied sand. This bank caving, and the consequent major disruption of drainage in an already poorly drained area, may have been the most significant effect of the earthquakes on the basin as far as man is concerned.

22. Detailed mapping of liquefaction phenomena from aerial photos has revealed their essentially continuous presence over an area of almost 4,000 square miles (Figure 10). The area involved is

considerably larger than that mapped by Fuller, extending farther to the northeast and across the Mississippi River into Kentucky and Tennessee. However, the basic distribution of more intense liquefaction has not changed. When looking at the size and nature of the entire area, it is not difficult for one to question whether this may be the most intense and widespread case of earthquake-induced liquefaction in the entire world. Irrespective of this, it is clear that hundreds of millions of cubic yards of sand were extruded to the surface.

23. The question of the distribution of sand blows and fissures as related to the epicentral position or positions of the earthquakes remains unresolved, but their relationship to other factors is evident. For example, the total area is more than 80 percent coincident with the younger braided-stream terraces and the areas of maximum intensity are perfectly coincident.

24. The relationship between the gross pattern of sand blows and fissures and basin topography is less apparent and is only now being analyzed (Figure 11). There are indications that in no case is topography the principal deterministic factor; however, it is evident that topography is relatively more important in the southern part of the area than in the northern part. The influence of topography is by way of its effect on water table positions and there is a definite relationship between high water tables and the more intense sand blow and fissure development in the southern part of the area.

25. The validity of the surface distribution of sand blows and fissures as being truly indicative of the actual area of ground disturbance is being investigated in a relatively unique manner. Thanks to the meticulous excavation techniques employed by archaeologists in investigating aboriginal mounds and village sites, carefully documented evidence of intense ground disturbance has been revealed.

26. Several archaeological sites in the area exhibit sand-filled fissures cutting through both natural deposits and cultural accumulations (Figure 12). The fissures are usually nearly vertical and vary in width from less than an inch to several feet. Typically they are highly sinuous in plan and sometimes can be followed for hundreds

of feet. Their control by cohesive-topstratum thickness is quite evident and they often reveal both horizontal and vertical offsets, but with no presently discernible regional pattern.

27. Thus far, records of archaeological site excavations have been examined for 29 sites, an estimated 75 percent of those for which data are available. Evidence of ground disturbance accompanied by the extrusion of liquefied sand has been observed at eight of these sites (Figure 13). All eight sites are within or very close to the mapped area of moderate to heavy sand blow and fissure occurrence, and all eight are well within the absolute area limits. This distribution helps confirm the indicativeness of the mappable surface features and reinforces the apparent restriction of major ground surface effects to the basin area. It must be pointed out, however, that this evidence cannot be conclusive since numerous sites with no observable disturbance occur within the area of sand blows and fissures. This probably only means that excavations were not extensive enough to encounter the disturbances.

28. Although the present study is less than one-third completed and field investigations have not been initiated, several interesting preliminary observations are emerging. The archaeological site data, in addition to their implications regarding the distribution of effects, also yield data on their temporal distribution. These data so far indicate no evidence of ground disturbance or liquefaction that cannot be attributable to the 1811-1812 earthquakes. Site stratigraphic information is reasonably complete for 500 or so years prior to 1811 and may be indicative of 1,000 or more years in some instances.

29. Regarding practical application of this study to engineering problems in the Lower Mississippi Valley, reexamination of the New Madrid earthquakes has revealed one virtually overlooked but very significant effect. This involves the consequences of the flooding which must have resulted from the extrusion of large quantities of water as well as sand.

30. Historical accounts of the earthquakes make repeated mention of water rising to waist height, and in the sunk lands area, of flooding

to depths of 20 to 30 ft. If one assumes no more than 6 in. of water rising to the surface in any one area, and hence producing not more than 5 or 6 ft of flooding in low basin areas, this would have created within several days a lake with an area of over 1,300 square miles (Figure 14). With this much water suddenly introduced into an area with poor drainage at the onset of the rainy season, and assuming major disruption of drainage-ways due to bank caving, it is conceivable that flooding could have persisted for months.

31. It is sobering to realize that flooding of this possible magnitude could occur today in the event of a repetition of the New Madrid earthquakes. Drainage is far superior to what it was in 1811; however, the artificial channels are at least equally susceptible to bank caving. It must also be appreciated that hundreds of miles of channel require considerable time for reexcavation.

32. It is certainly not premature to recognize in all aspects of basin planning the possibility of widespread flooding, particularly since the affected area has a population of over 30,000. However, additional work is needed before any realistic probability of risk can be estimated. Certain aspects require particular emphasis.

33. For example, there are persistent suggestions that the New Madrid earthquakes were truly unique in regard to major surface effects. Possible explanations for this are quite tenuous but nevertheless present.

34. Considering the close relationship between the area of liquefaction and the inferred area of flooding (Figure 15), and keeping in mind influences of water table positions and the sequence of seismic events, is it possible that flooding resulting from the December 1811 earthquake could have made the area extraordinarily susceptible to further liquefaction during the January or February 1812 earthquakes? Historical accounts need to be examined in detail for substantiation of a possible compounding effect. Consideration must also be given to another question relevant to this possibility. This concerns the degree to which substratum sands may be densified as a result of having liquefied. Is it reasonable to suspect that the sands are more dense and hence less susceptible to further liquefaction after a major earthquake?

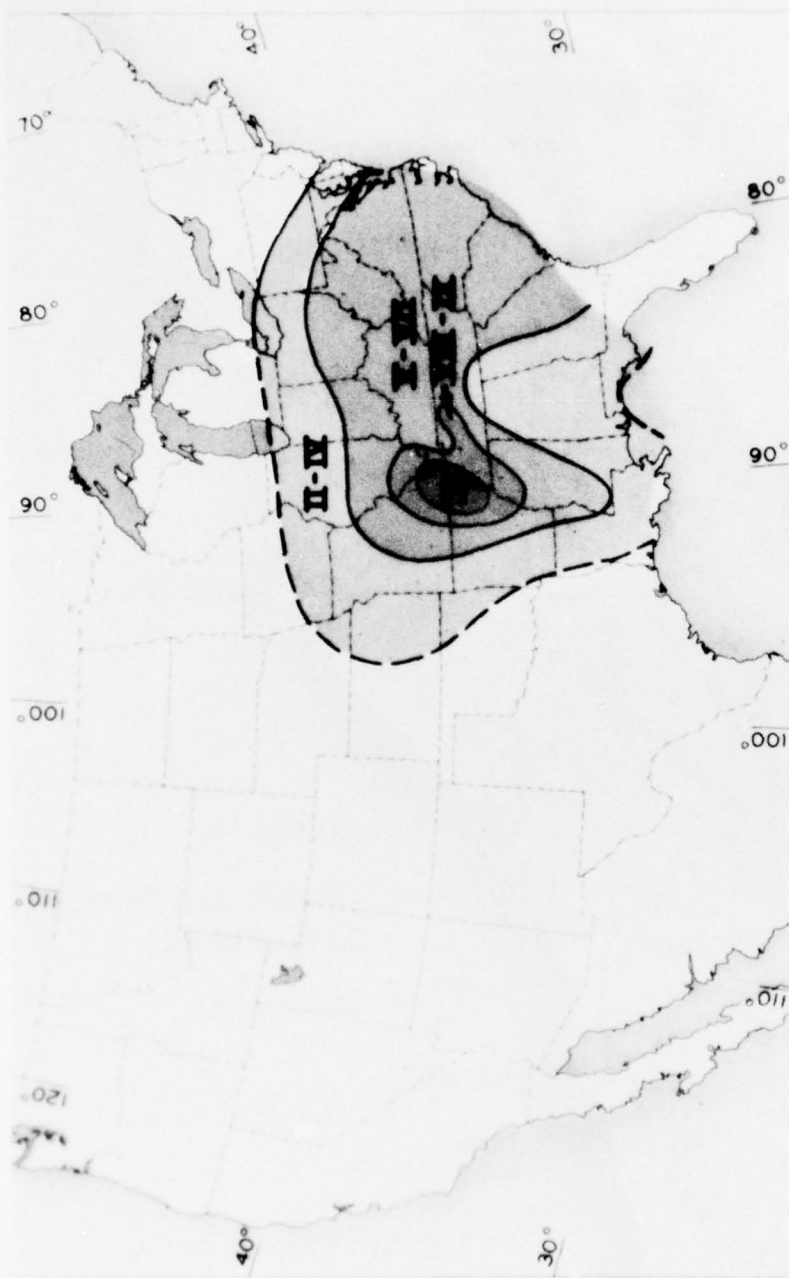
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ISOSEISMAL MAP
NEW MADRID EARTHQUAKE OF DEC. 16, 1811
MODIFIED MERCALLI INTENSITY SCALE
AFTER STEARNS AND WILSON, 1972

FIGURE 1

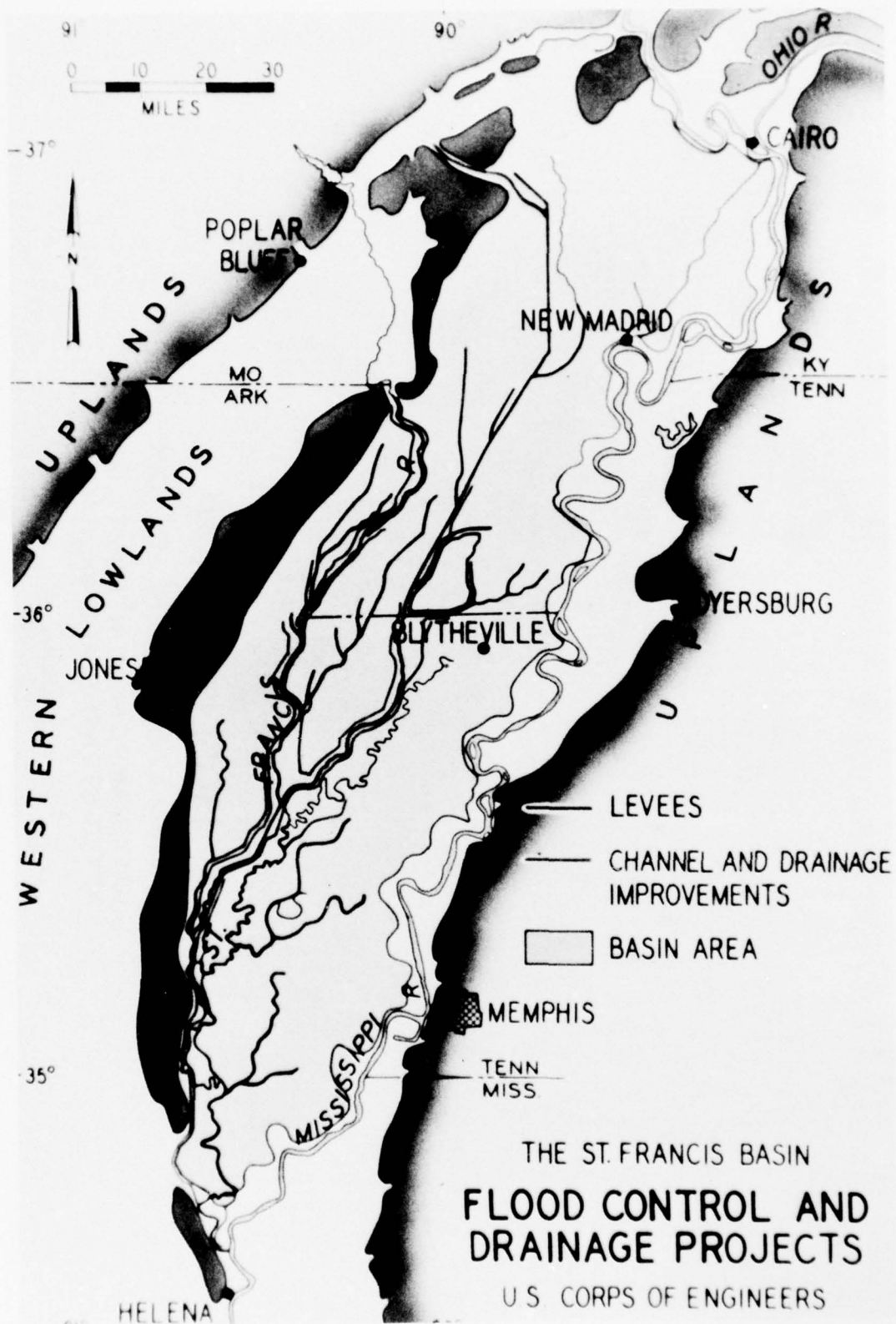


FIGURE 2

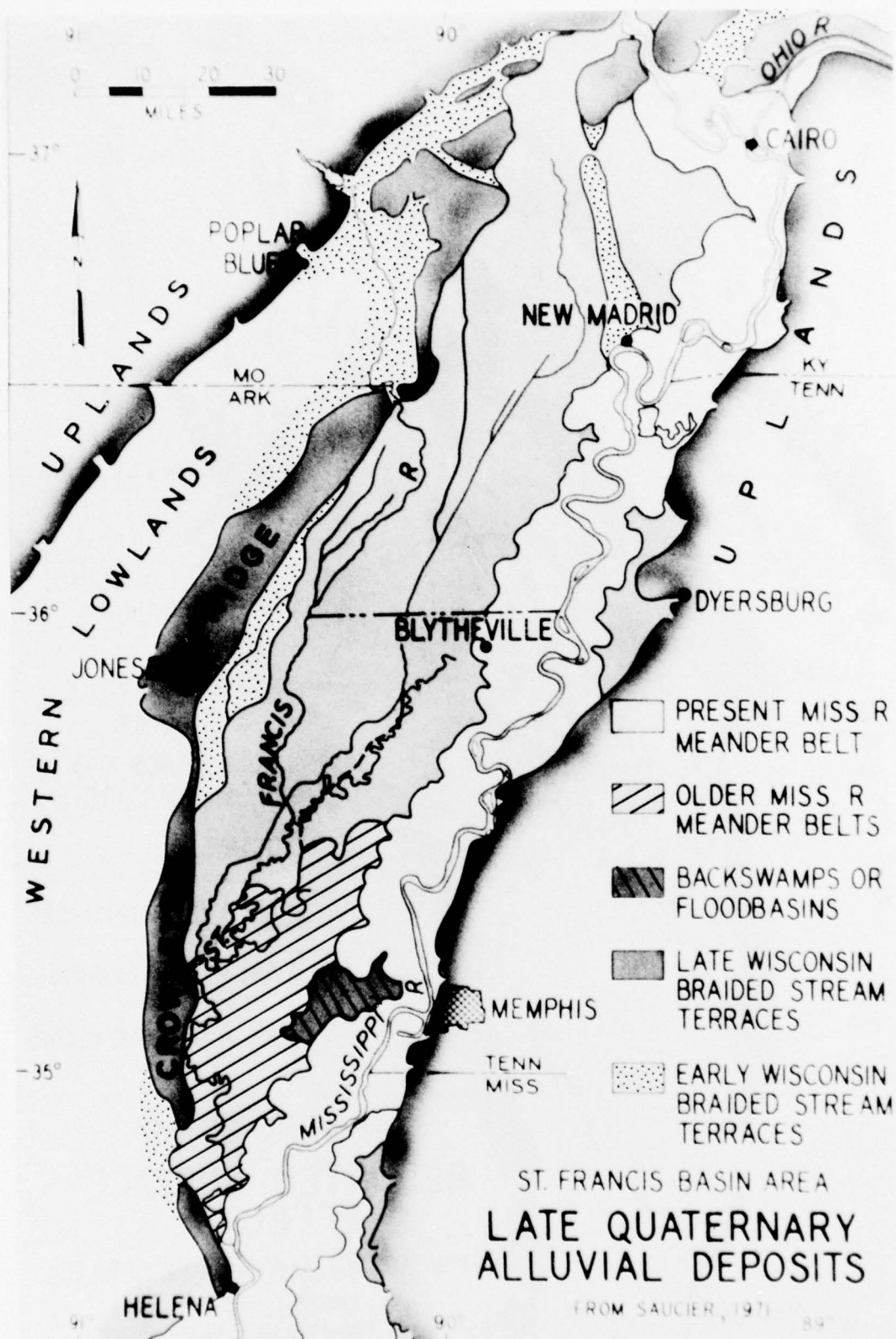


FIGURE 3

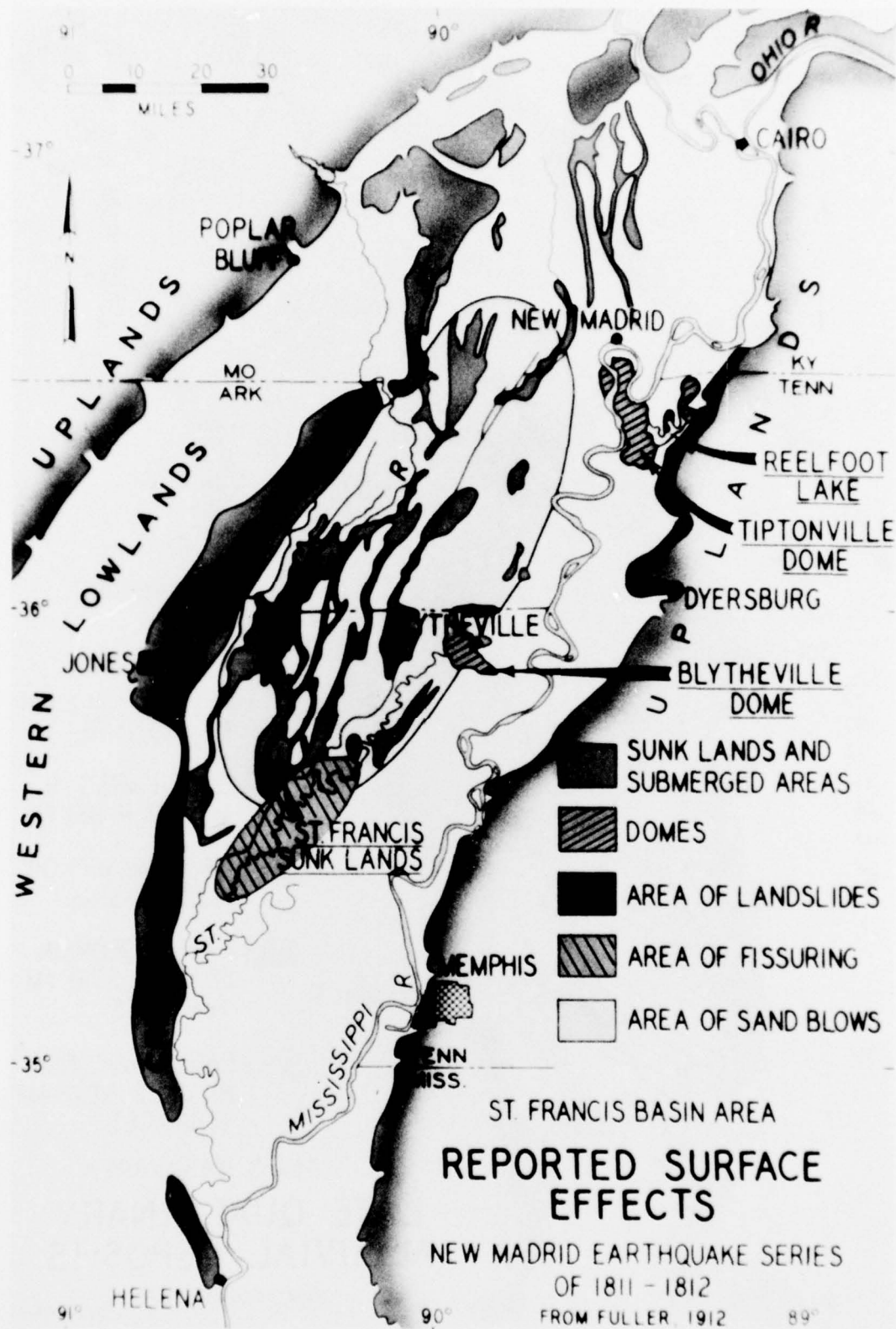


FIGURE 4

ORIGIN OF THE ST. FRANCIS SUNK LANDS

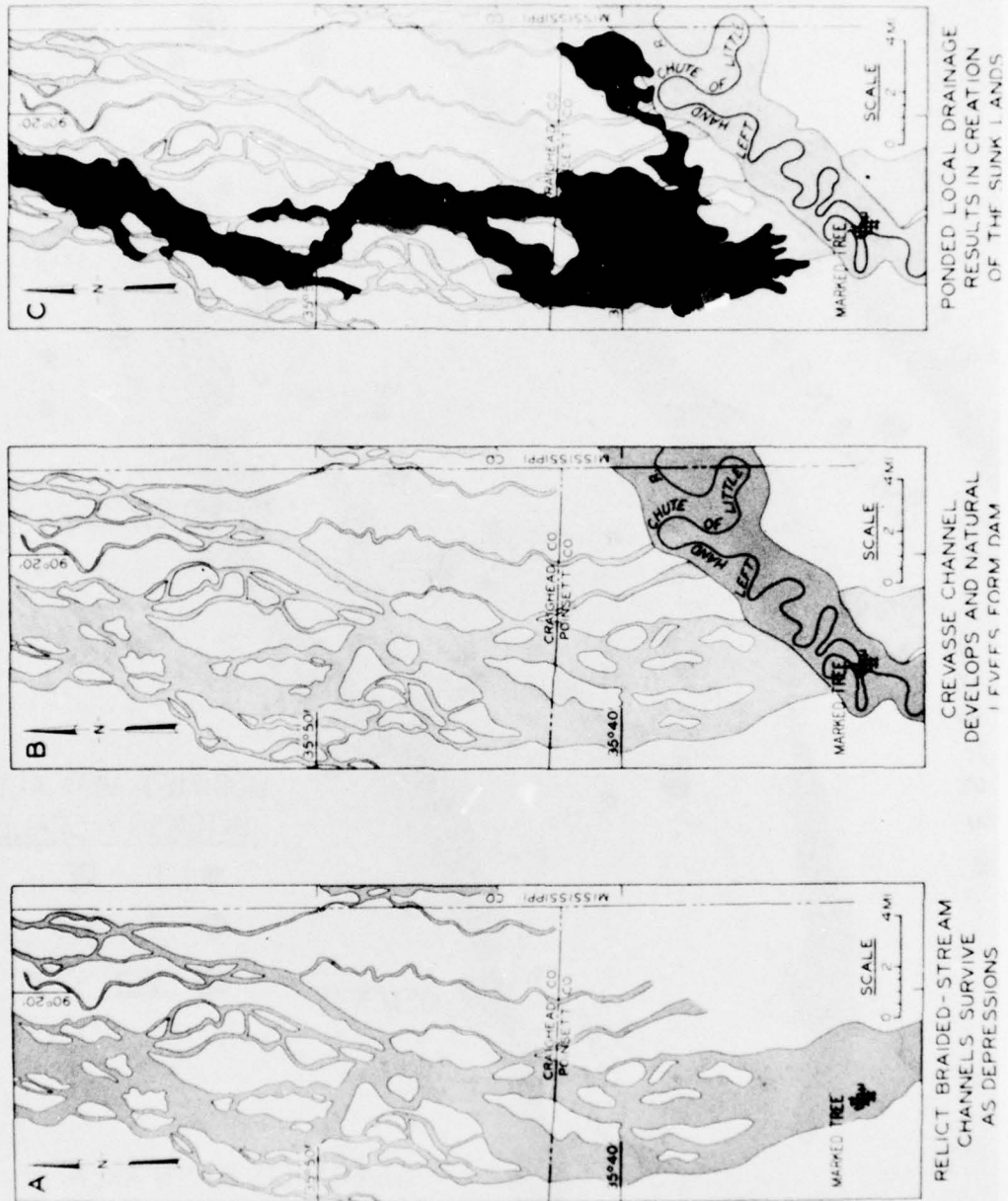


FIGURE 5

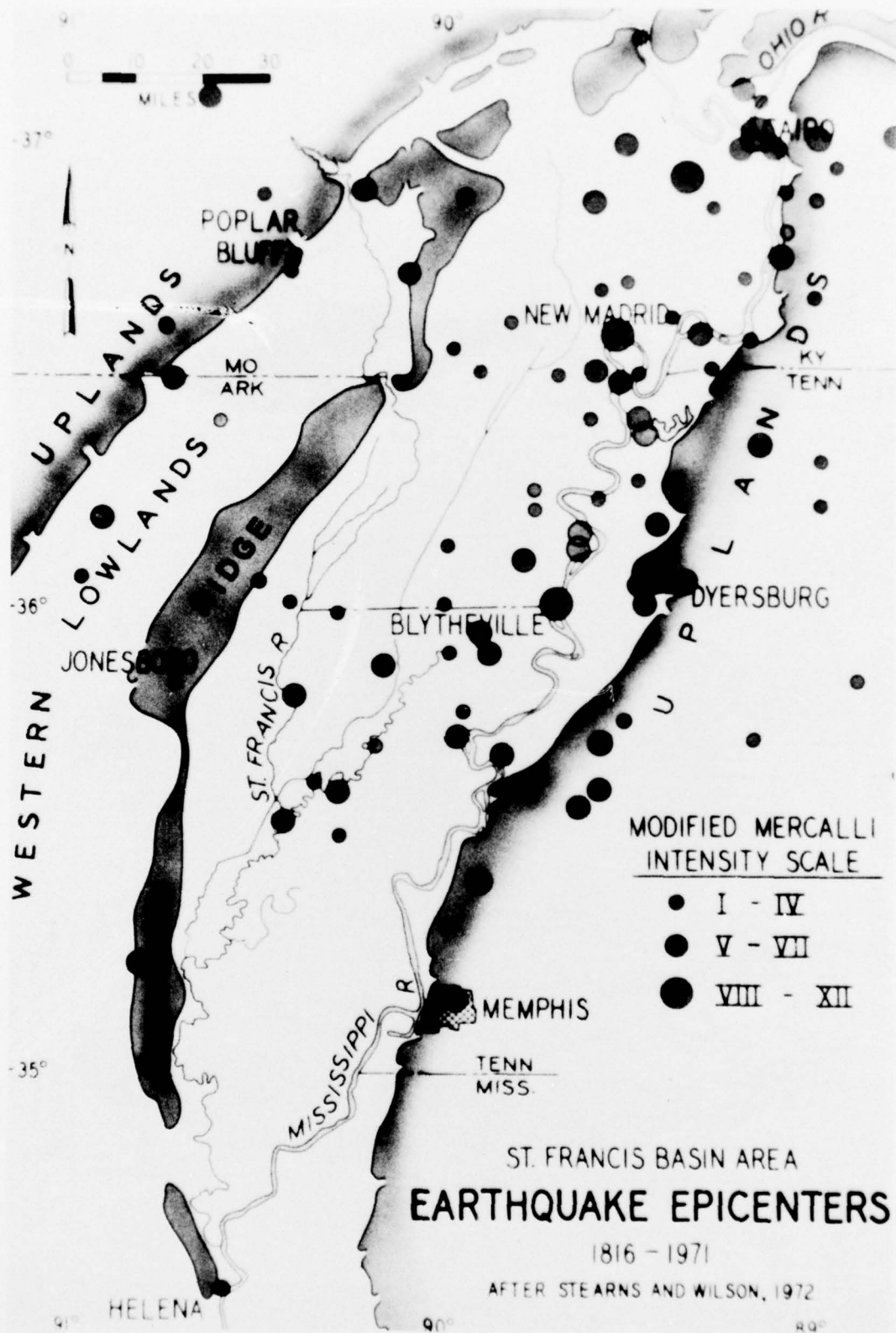


FIGURE 6



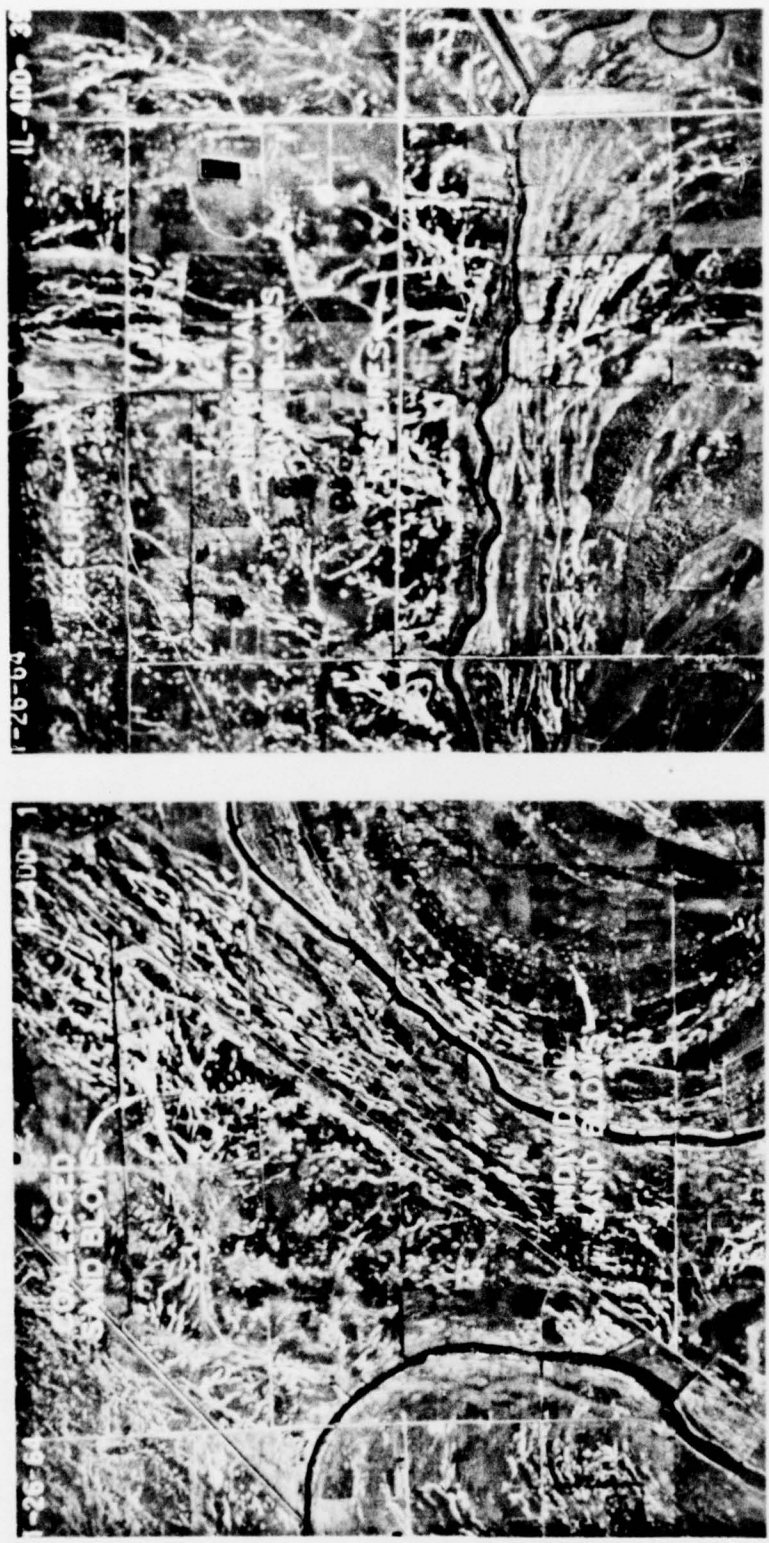
HELENA, MONT
EARTHQUAKE OF 1935



SAN FRANCISCO, CALIF
EARTHQUAKE OF 1906

SURFACE MANIFESTATIONS OF EARTHQUAKE-INDUCED LIQUEFACTION

FIGURE 7

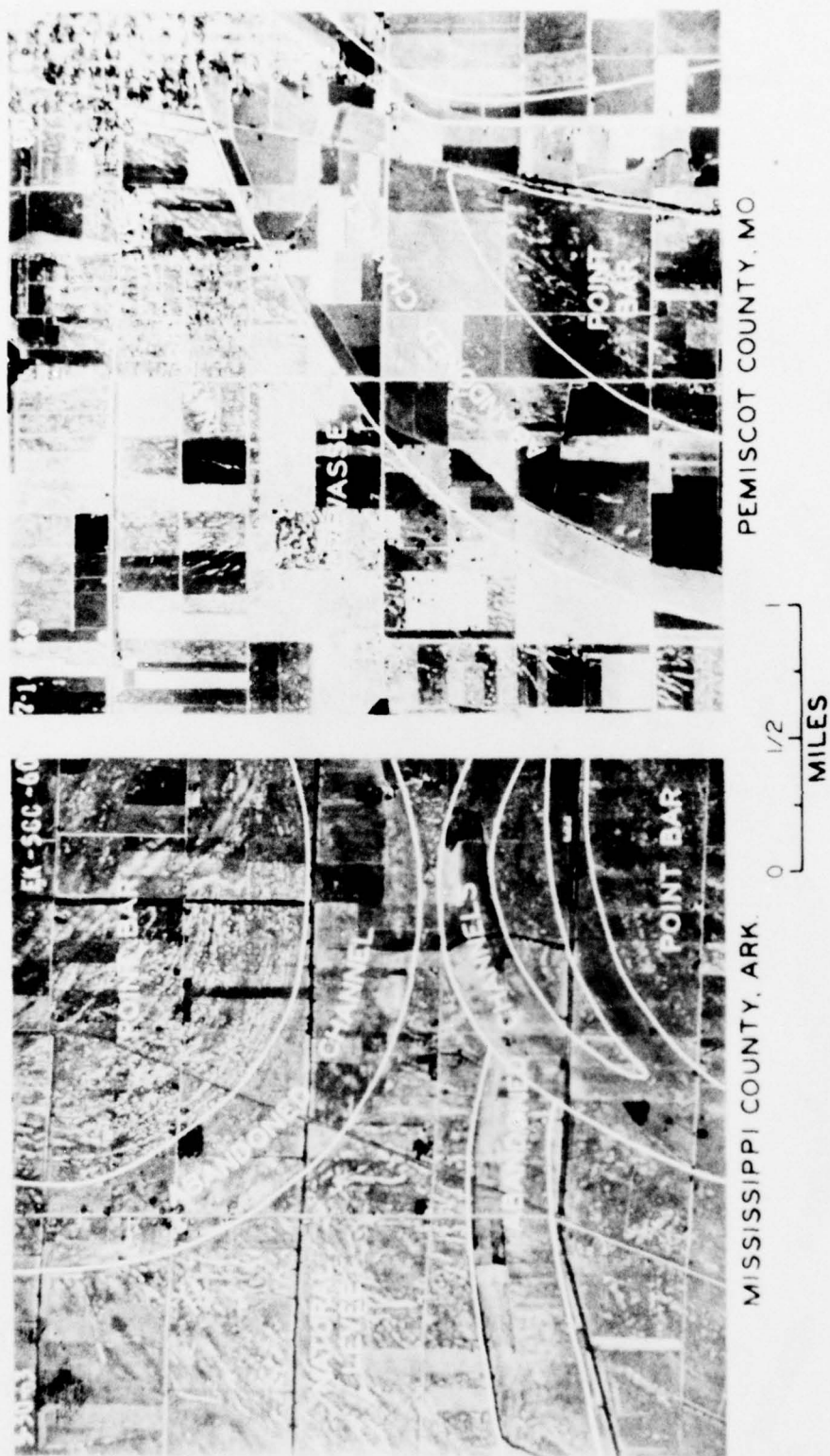


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ST. FRANCIS BASIN AREA
SAND BLOWS AND FISSURES CAUSED BY
THE NEW MADRID EARTHQUAKES

FIGURE 8



ST. FRANCIS BASIN AREA
 INFLUENCE OF LOCAL GEOLOGY ON CHARACTER
 OF SAND BLOWS AND FISSURES

FIGURE 9

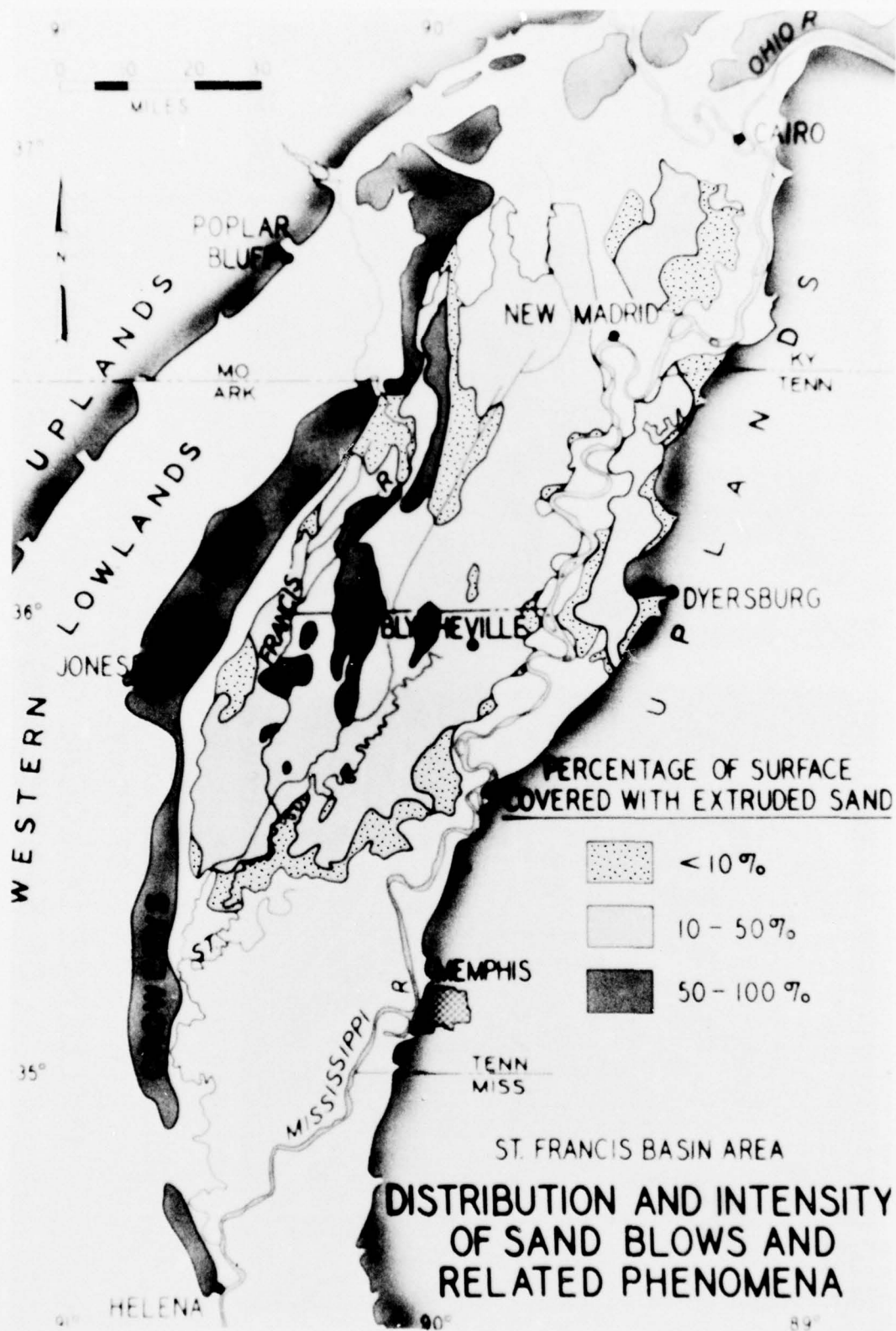
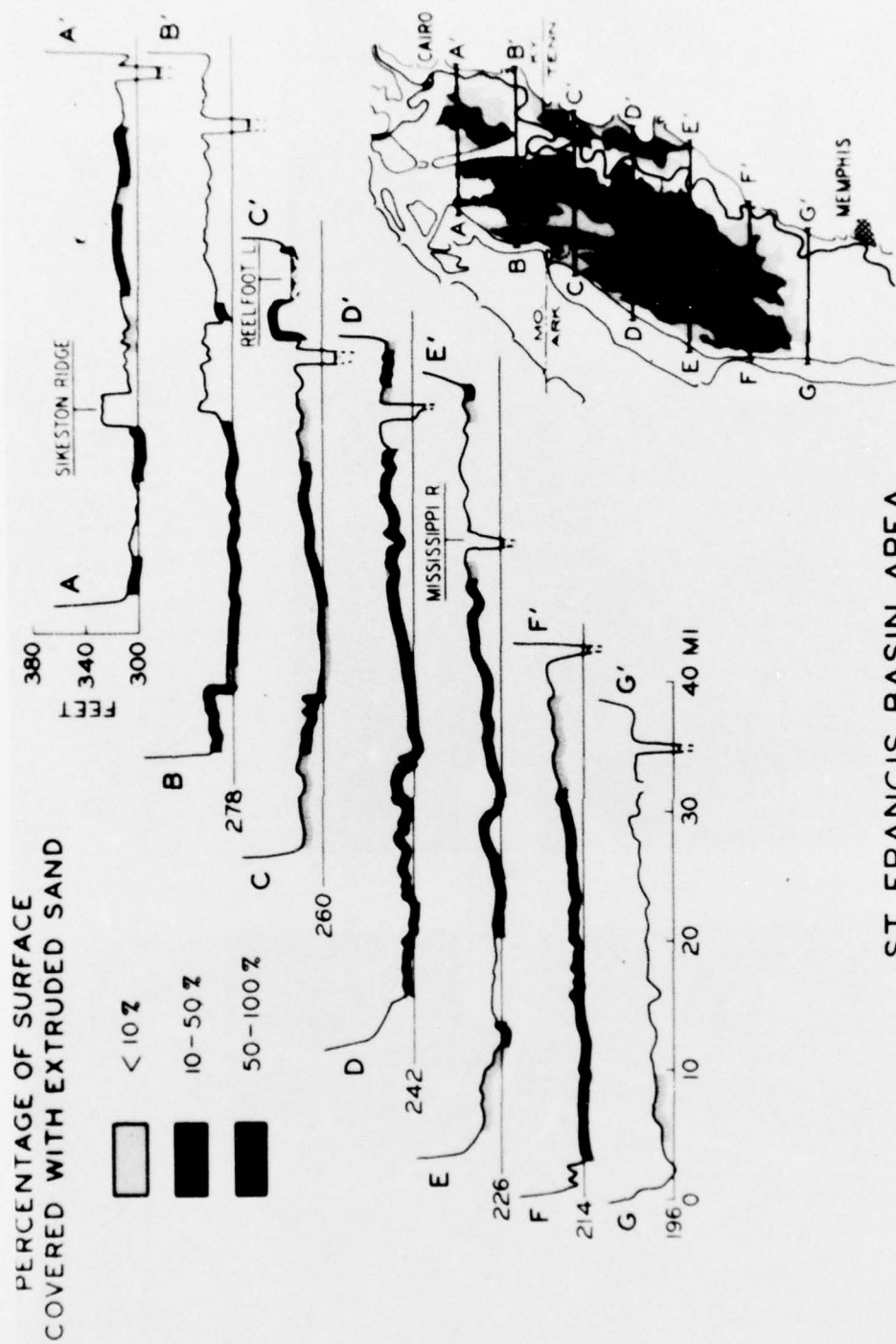
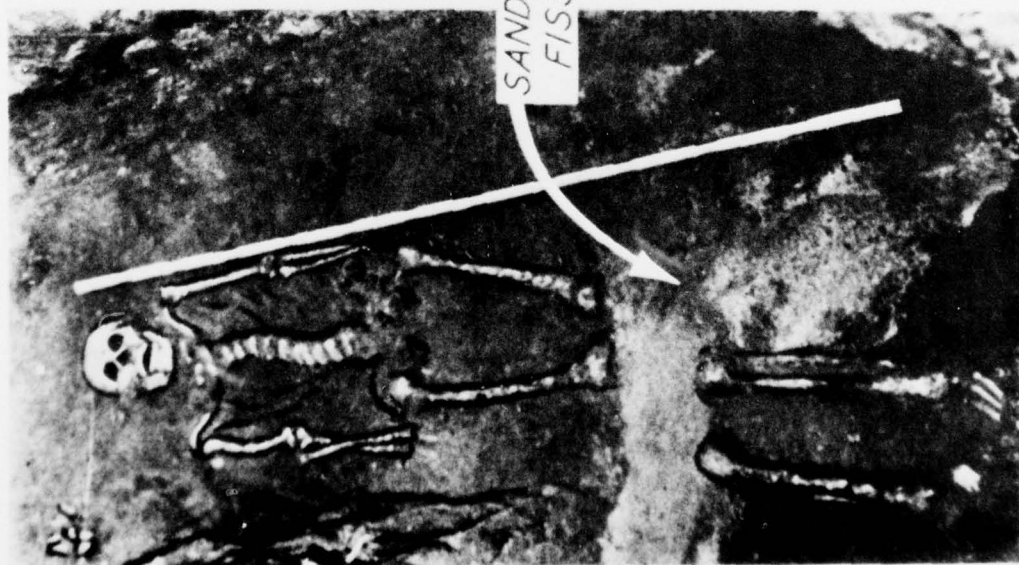
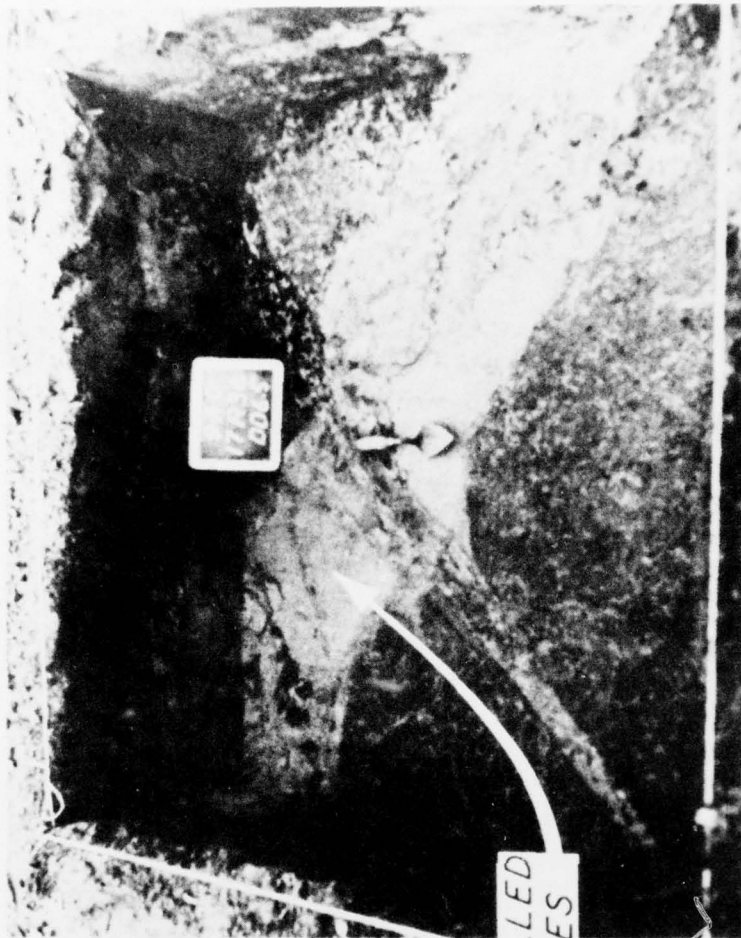


FIGURE 10



ST. FRANCIS BASIN AREA
RELATIONSHIP OF SAND BLOWS AND FISSURES
TO BASIN TOPOGRAPHY



EXAMPLES OF EARTHQUAKE-INDUCED GROUND
DISTURBANCE IN ARCHAEOLOGICAL SITES

FIGURE 12

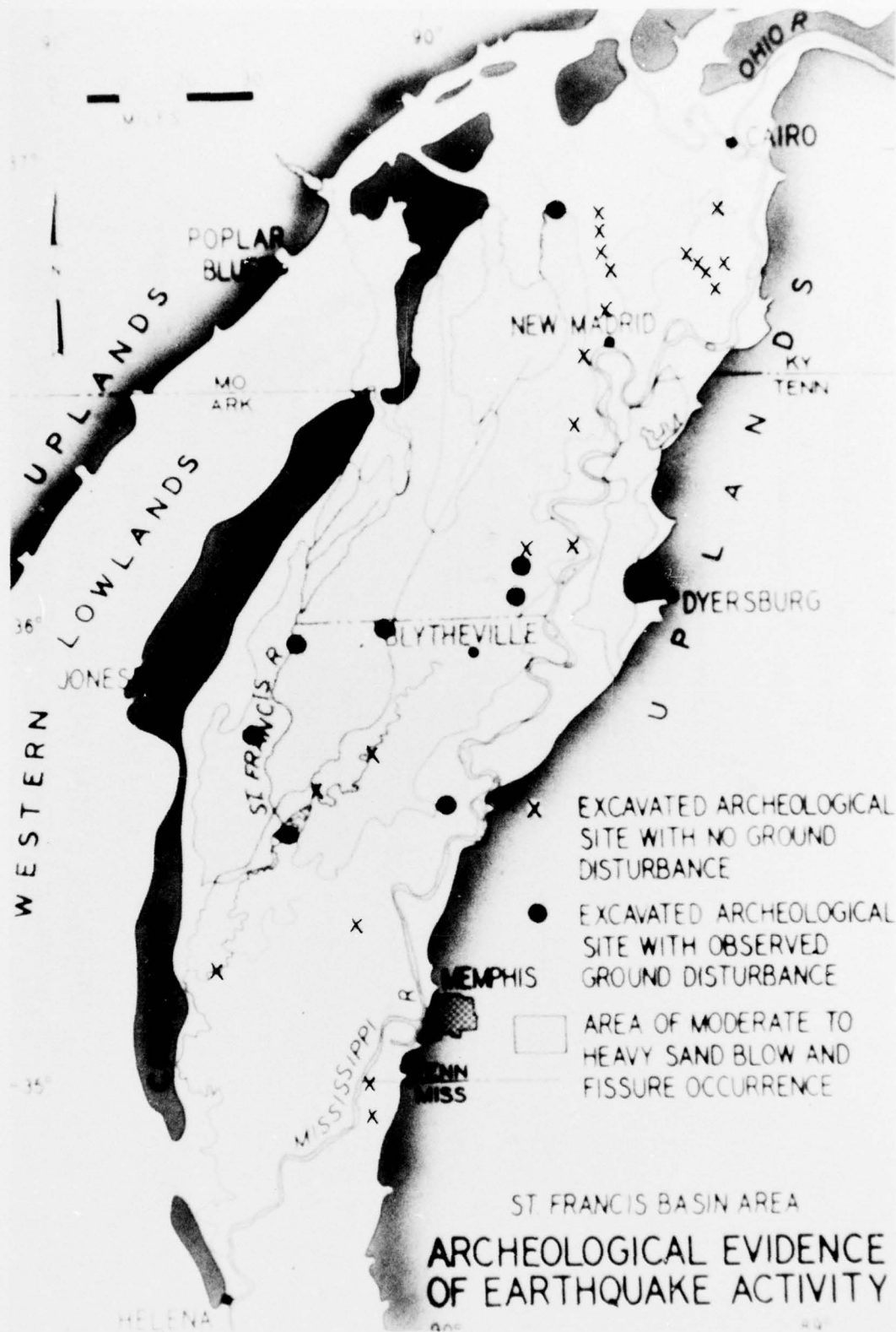
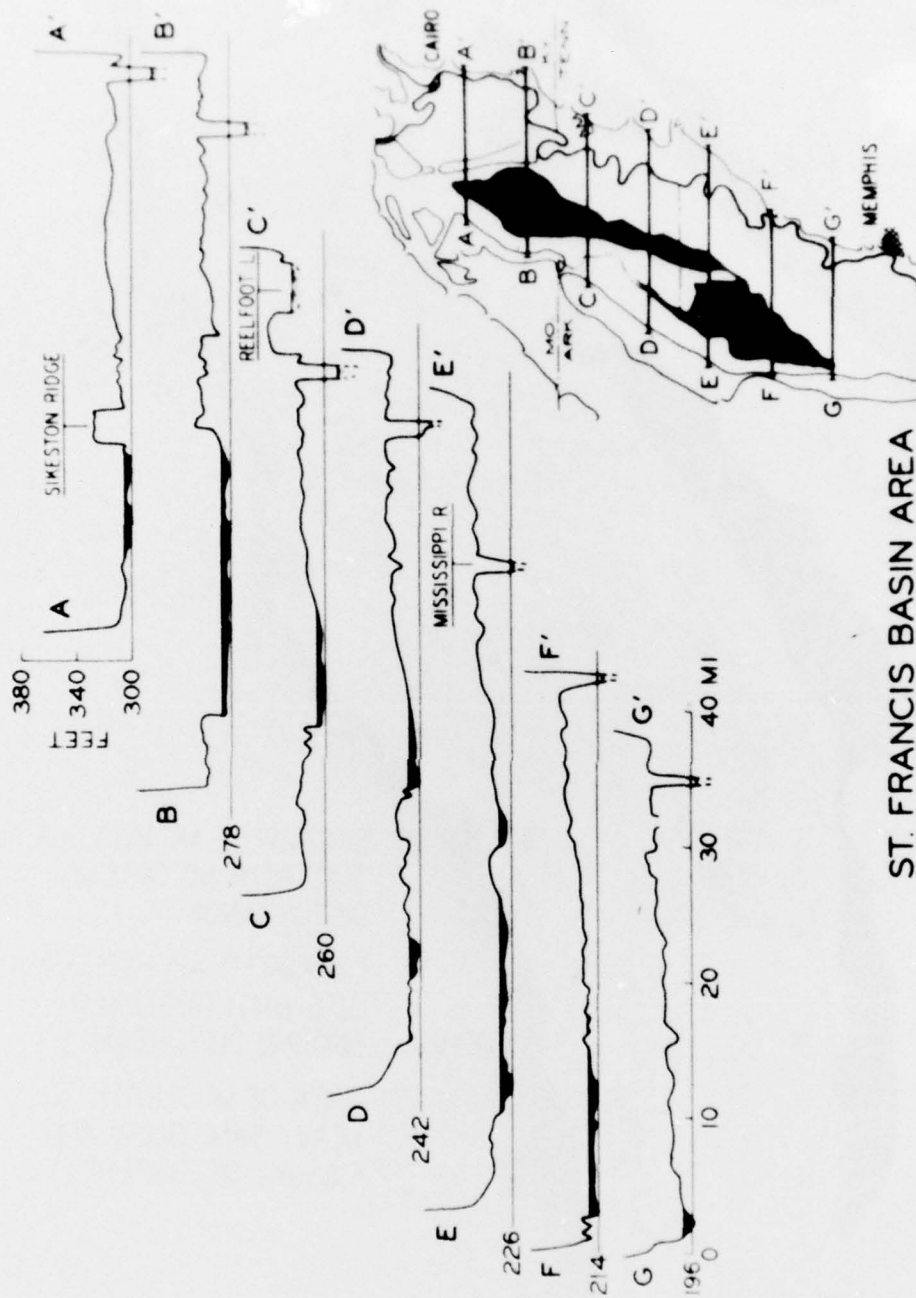


FIGURE 13

FIGURE 14



ST. FRANCIS BASIN AREA
 PROBABLE MINIMUM EXTENT OF FLOODING
 DUE TO EARTHQUAKE-INDUCED LIQUEFACTION

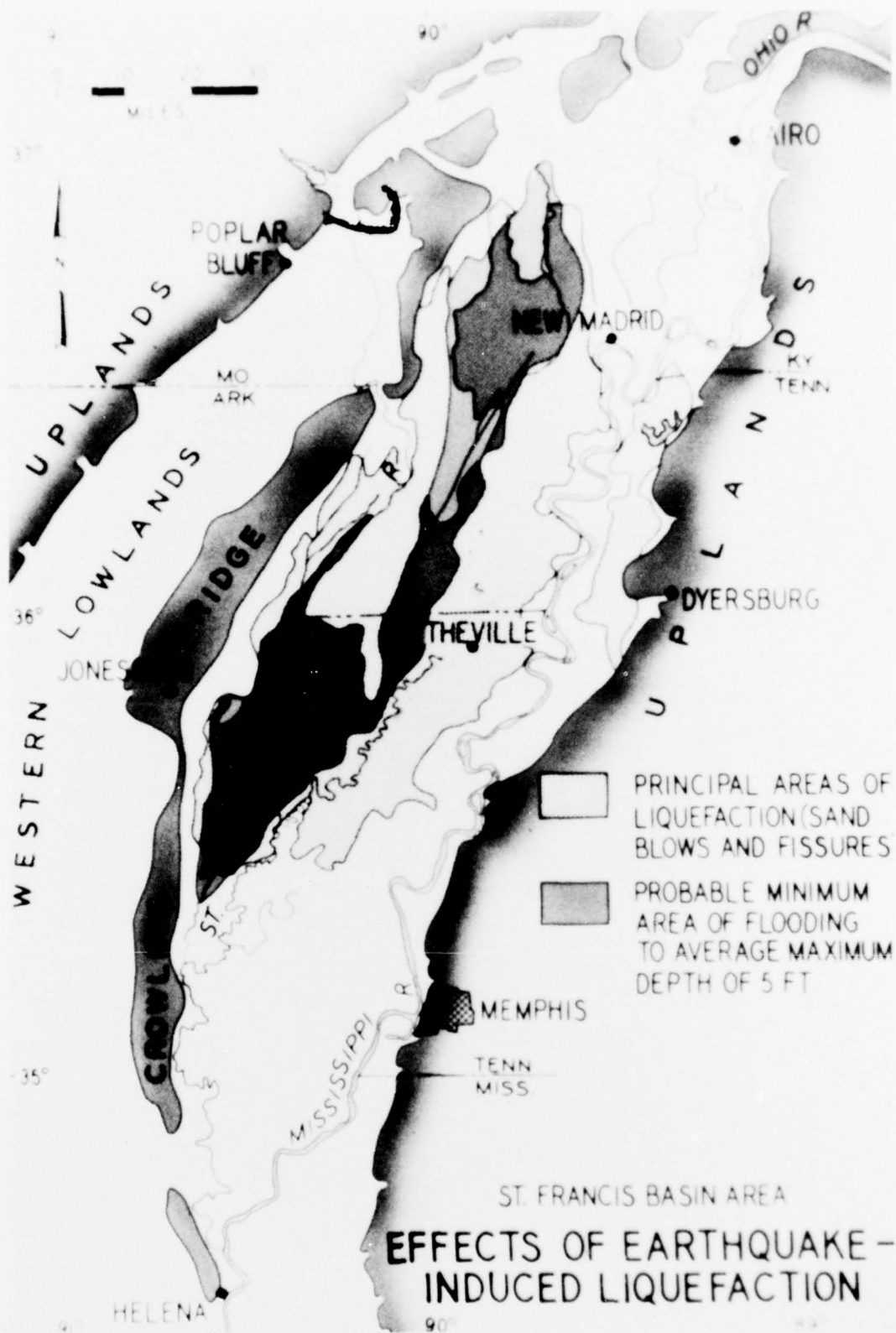


FIGURE 15

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References: p. 11.

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